First stars in the universe (an update)

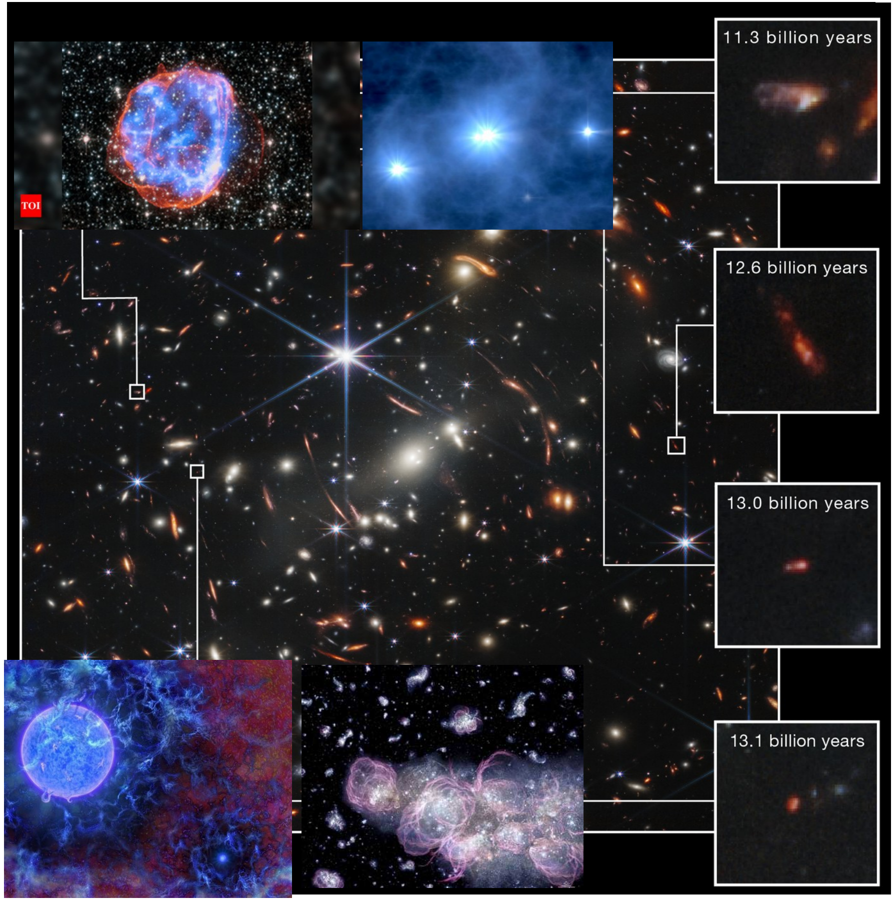
Outline:

Pop III: single/binary stars an Population

Pop III: simulations

Pop III: detectability

→ with e.m. signals
→ with GW signals



Finanziato dall'Unione europea NextGenerationEU

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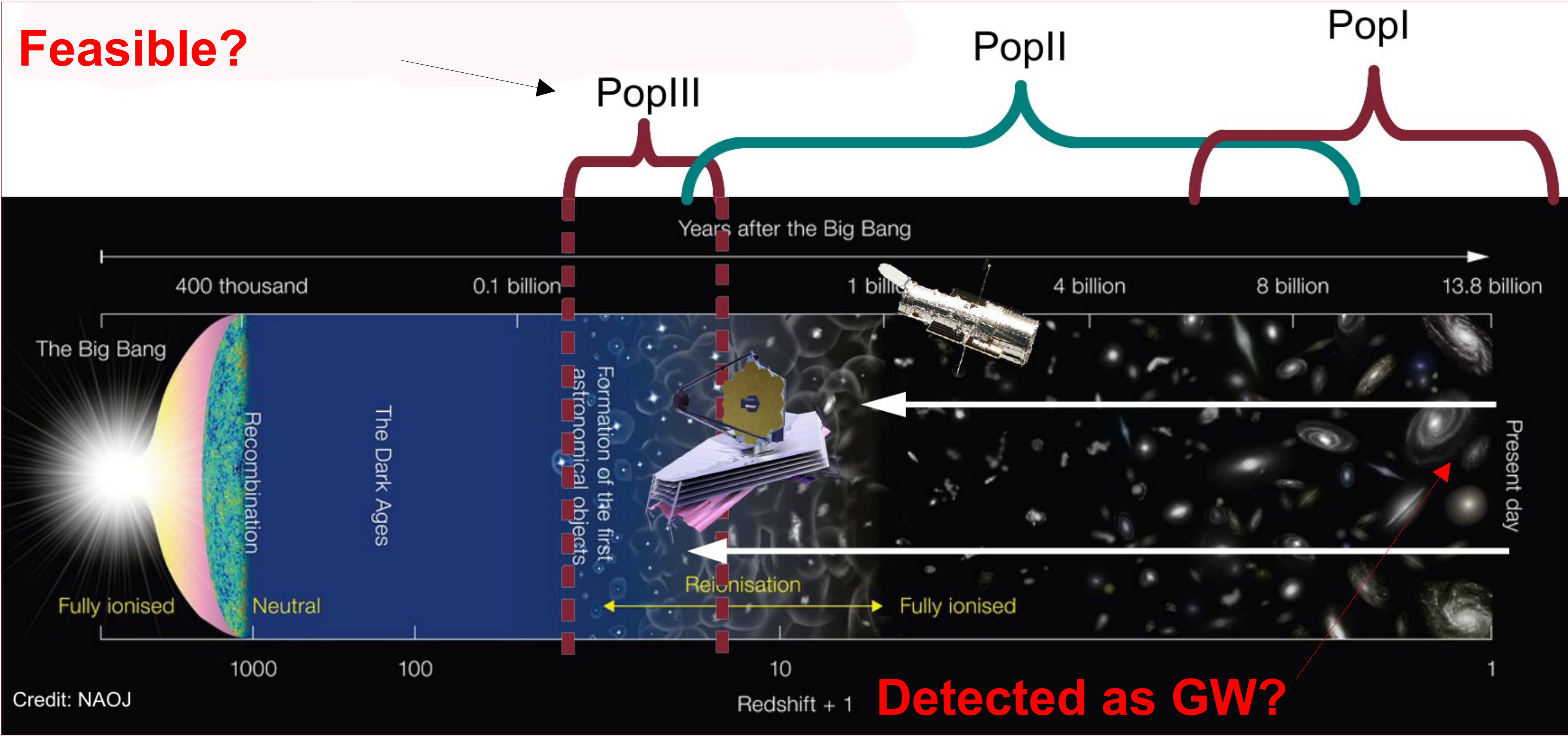
Luca Graziani

Vulcano Workshop 2024, Ischia Italia, 28/05/2024

A new era of GW Astronomy, Astrophysics, Cosmology

Feasible?



Detected as GW?

Future: both E.M. and G.W. accessing high-z universe

First stars: detectability?

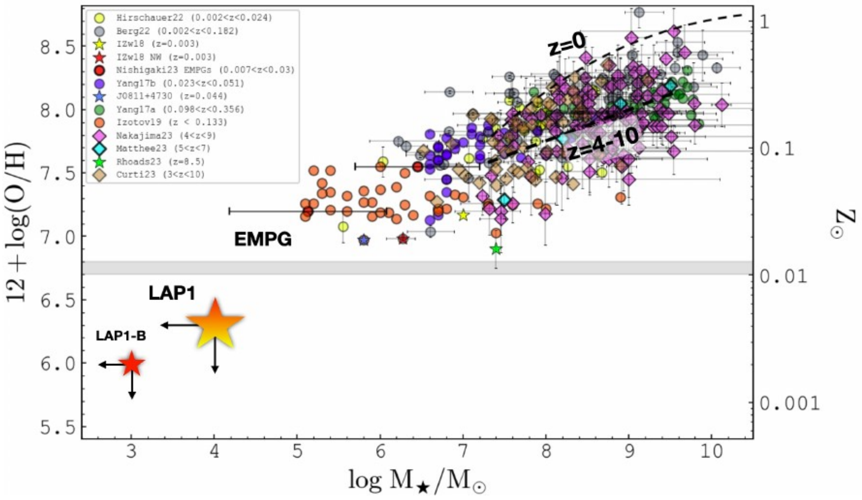
- **Open Problems in interpreting tentative detections in e.m.:**

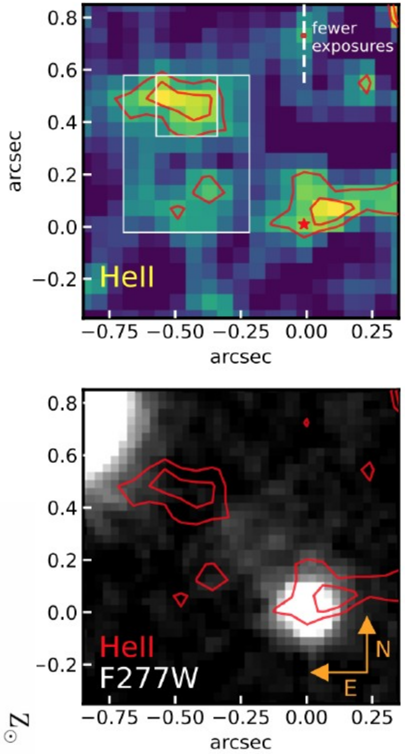
1. Maiolino et al. 2023: JWST-Jades

   JWST-JADES. Possible Population III signatures at z=10.6 in the halo of GN-z11 (ArXiV:2306.00953)

2. Vanzella et al. 2023: LAP1

   An extremely metal-poor star complex in the EoR: Approaching Population III stars with JWST

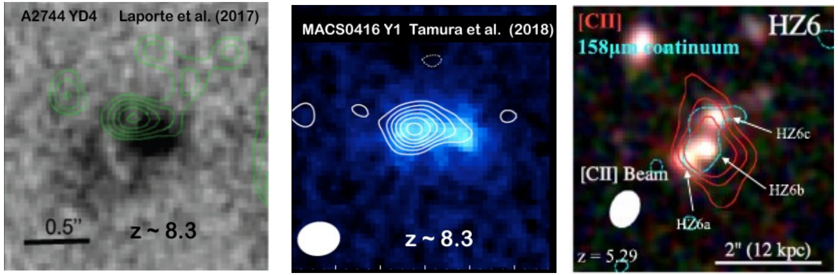




A census of high-z galaxies requires dusty galaxies

Single, normal star forming galaxies detected in CII, OIII at z > 6 also having a dusty ISM With $\log(M_d/M_{sun}) > 5.5$

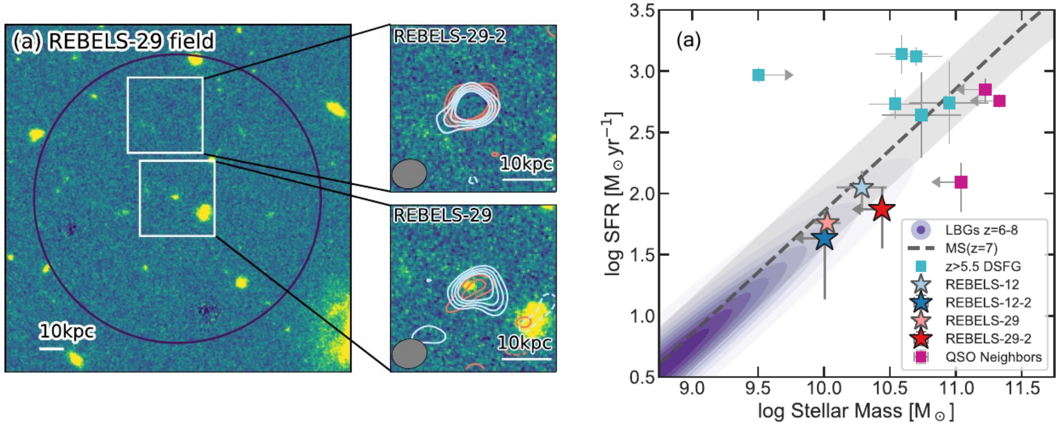
Normal galaxies chemically evolved even within EoR?
Conclusion biased by the small sample?



See Graziani et al. MNRAS 2020, for a collection of obs. systems

Serendipitous detection of normal, dust obscured galaxies at z > 6.

Are we missing star forming systems in the EoR?



Y. Fudamoto, P. Oesch & Rebels Collaboration, Nature, 2021

First stars: definition and theoretical open issues

- **Defined as stellar objects with metallicity $Z_* \leq 10^{-4}\ Z_\odot$**

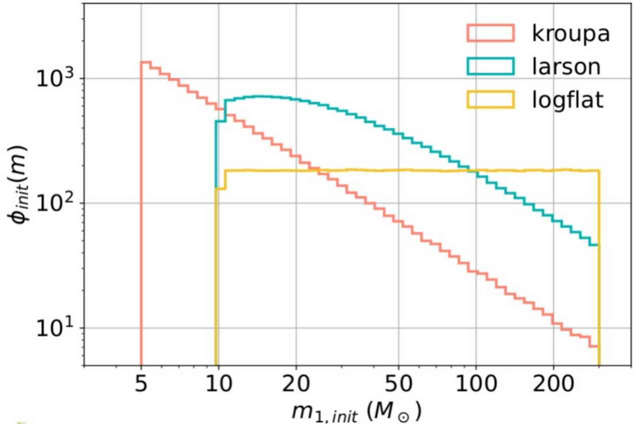
- **Open Problems in modelling the single stellar populations:**

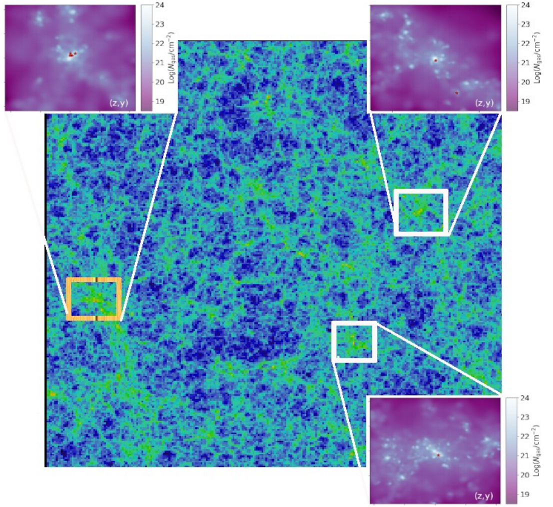
  1. Physical processes regulating star formation and evolution are mainly known at $Z_* \geq 10^{-2}\ Z_\odot$.
  2. Mass function unknown, probably spanning in $M_* \sim 10\text{-}10^3\ M_\odot$
  3. Short lifetimes $t_* <$ 3 Myr
  4. End of life as PISN or BH
  5. Spectral emission?

     → Pop III models uncertain in many physical aspects.

- **Open Problems in modelling galactic environments:**

  1. Extremely metal poor environments (mini-halos) still not accessed
  2. Redshifts of Pop III star formation alone still not accessible
  3. E.M. emission confused by other sources : Bhs, stellar binaries could trigger HeIIλ1640 emission line.

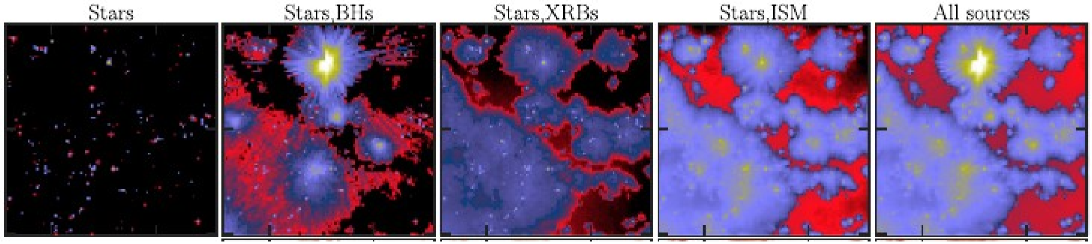




First stars: definition and theoretical open issues

- **Open Problems in modelling cosmic PopIII star formation:**

1. Cosmological evolution linked to feedback during EoR



(Eide M., Ciardi, B., **L.G.** et al., MNRAS, 2020)

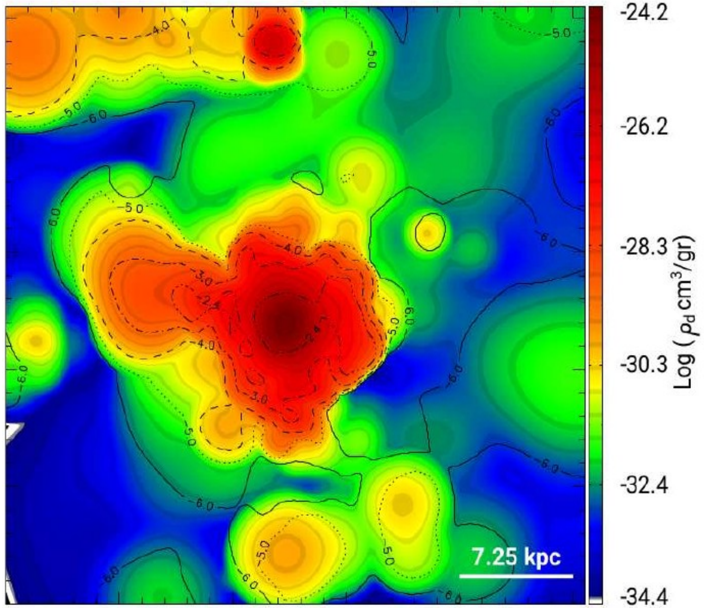
Pop III suppression:

→ **Radiative Feedback** → **Reionization**

→ **Chemical Feedback** → **Cosmic metal enrichment**

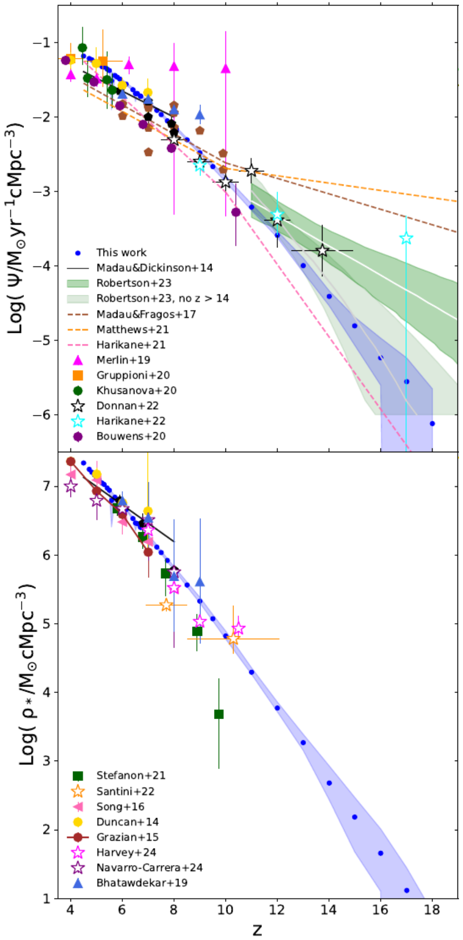
2. When does Pop III star formation end?

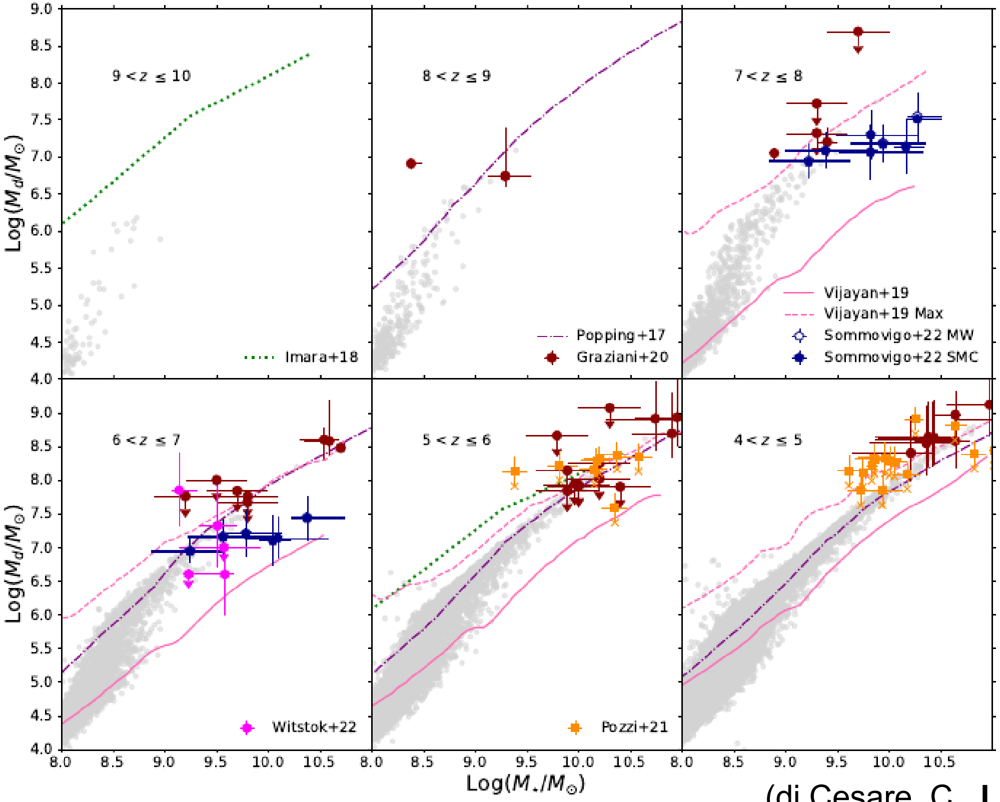
→ Transition Pop III/II



(Graziani L. et al., MNRAS, 2020)

Scaling relations connecting M*, SFR, Z, Md during EoR

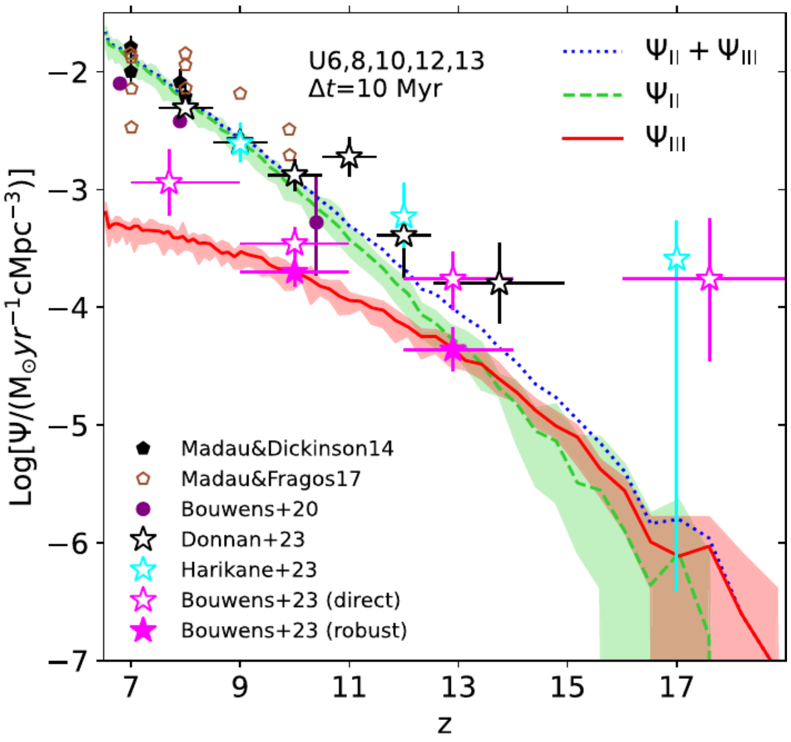


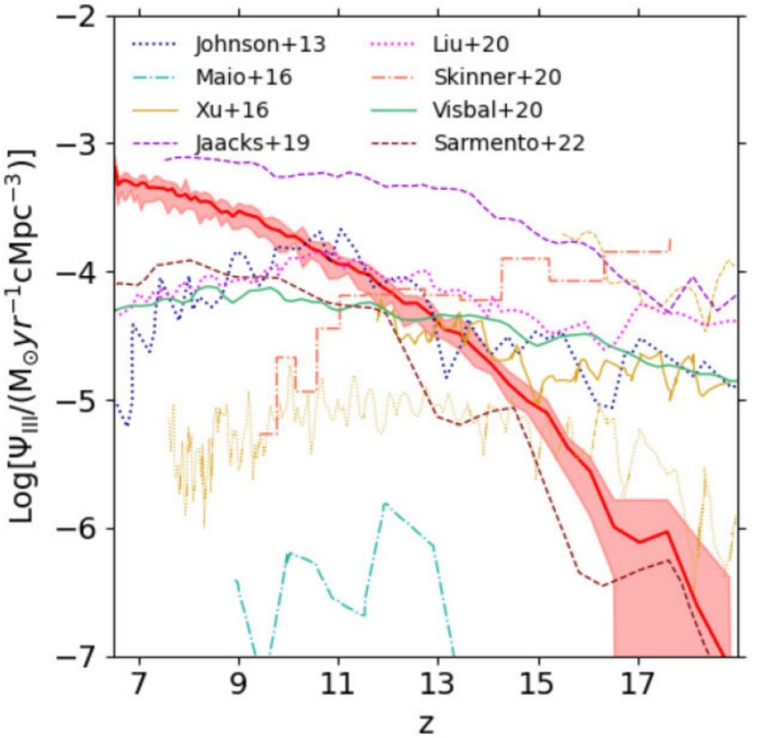


(di Cesare, C., **L.G.** et al., MNRAS, 2023)

Cosmic Pop III star formation

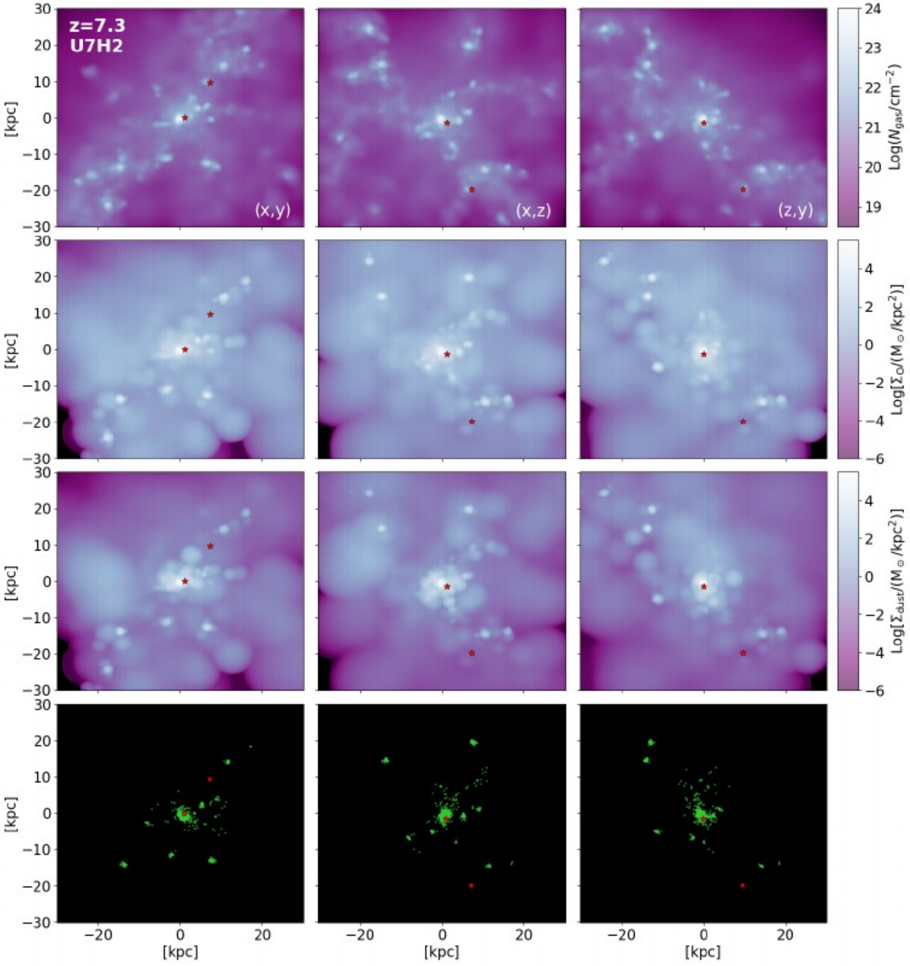
Venditti, A., **L.G.** et al., MNRAS, 2023





Future: resolving mini-halos

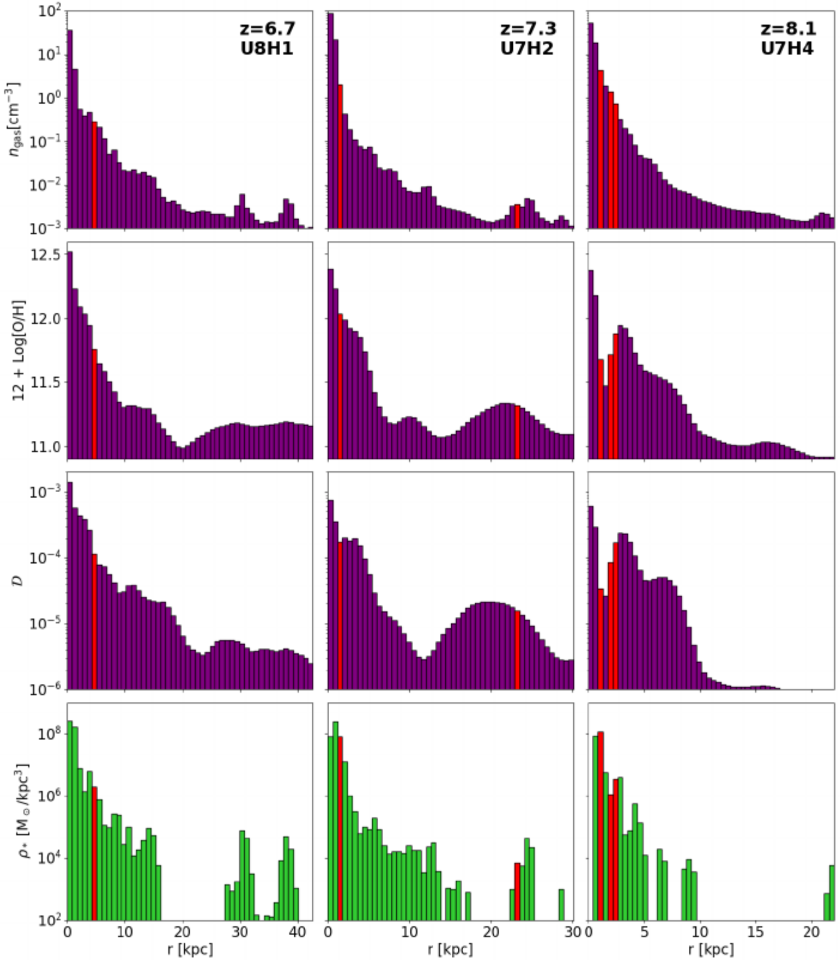
Pop III hosts & Detectability

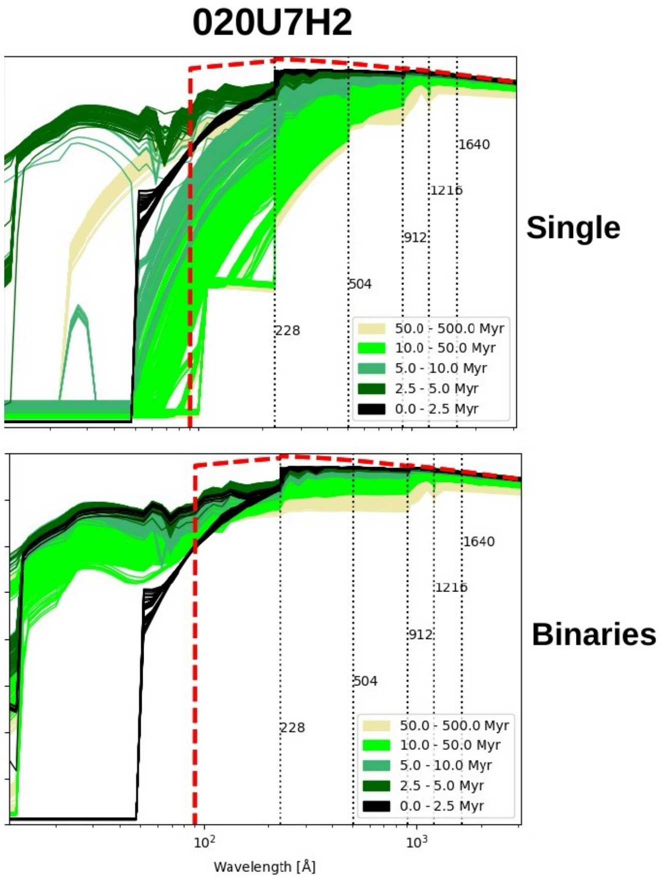


Venditti, A., **L.G.** et al., MNRAS, 2023

Halo ID	$\mathrm{Log}M_*/M_\odot$	$\mathrm{Log}M_3/M_*$	SFR $[M_\odot\ yr^{-1}]$	$\mathrm{Log}M_{dust}/M_\odot$	$\mathrm{Log}M_{gas}/M_\odot$	$\mathrm{Log}M_{DM}/M_\odot$
			$z = 6.7$			
U8H0	10.37	-4.05	176	8.27	11.25	12.04
U8H1	**9.97**	**-3.66**	**61**	**7.61**	**11.19**	**11.94**
U7H6	9.90	-3.50	42	7.75	10.85	11.61
U13H0	9.75	-3.44	53	7.29	10.97	11.73
			$z = 7.3$			
U6H0	10.00	-3.59	67	7.83	10.85	11.66
U8H0	9.99	-3.68	78	7.78	11.08	11.85
U8H1	9.83	-3.52	57	7.46	10.96	11.70
U7H2	**9.62**	**-2.91**	**46**	**7.16**	**10.81**	**11.56**
U12H2	9.50	-3.19	25	7.05	10.81	11.57
U8H4	9.49	-3.18	25	7.21	10.66	11.41
U6H2	9.44	-3.13	18	7.14	10.63	11.40
U7H3	9.44	-2.83	20	6.76	10.80	11.55
U10H2	9.41	-2.80	26	6.86	10.63	11.40
U13H2	9.38	-3.07	17	6.87	10.59	11.35
U13H0	9.35	-2.69	19	6.92	10.73	11.46
U10H3	9.33	-3.02	15	6.87	10.62	11.35
U7H95	9.00	-2.38	7	6.10	10.18	10.59
			$z = 8.1$			
U12H3	9.40	-3.08	18	7.15	10.42	11.20
U8H2	9.37	-3.06	24	6.88	10.65	11.39
U12H1	9.35	-3.04	23	6.80	10.63	11.37
U8H1	9.33	-2.93	28	6.76	10.68	11.44
U7H4	**9.18**	**-2.26**	**18**	**6.58**	**10.55**	**11.30**
U8H5	9.02	-2.61	11	6.46	10.45	11.20
U10H2	9.01	-2.70	10	5.95	10.43	11.18
U10H5	8.99	-2.68	8	6.51	10.22	10.99
U6H5	8.97	-2.65	8	6.25	10.37	11.12

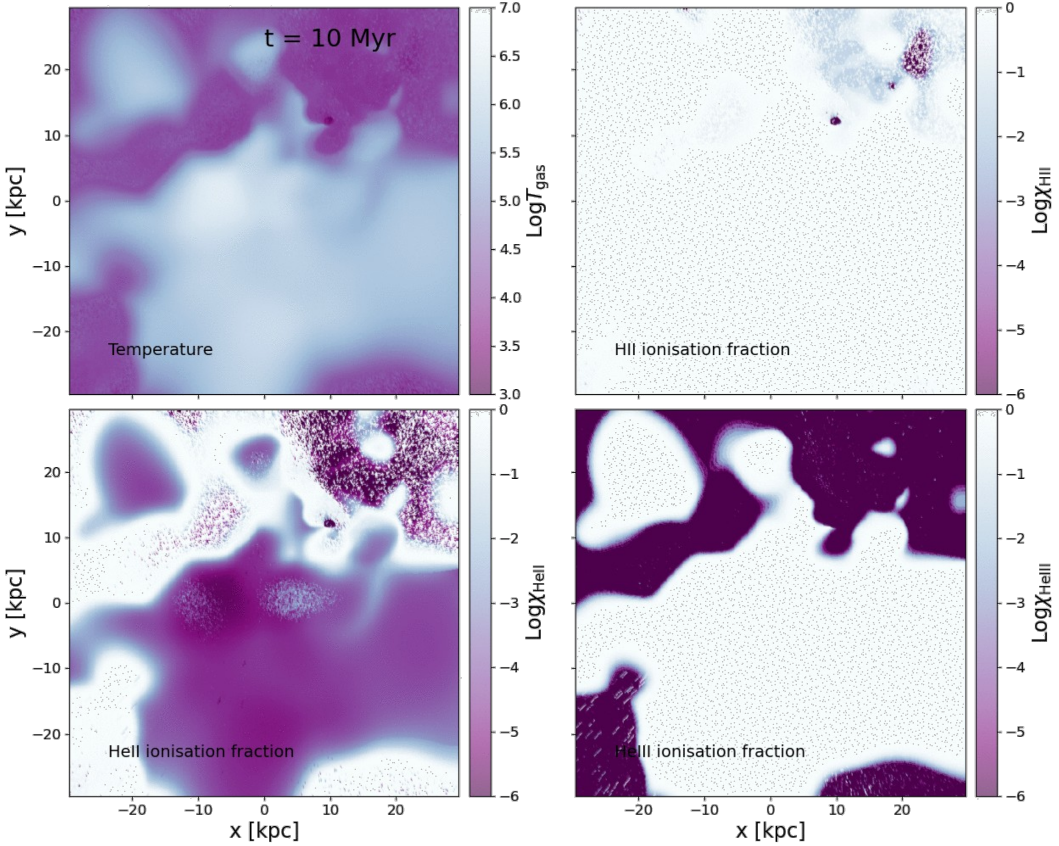
Can we recognize these Pop III stars?





Can we recognize these Pop III stars?

Alessandra Venditti, LG, R. Schneider,
L. Pentericci, et al., in prep.



RT simulations tracking the escaping Spectrum can predict transient HeII lines

Pop III and X-rays binaries could be Confused in a low metallicity case..

Archaeology as complementary tool

i.e.

Gravitational Waves from Pop III binaries

Cosmic archaeology with massive stellar black hole binaries

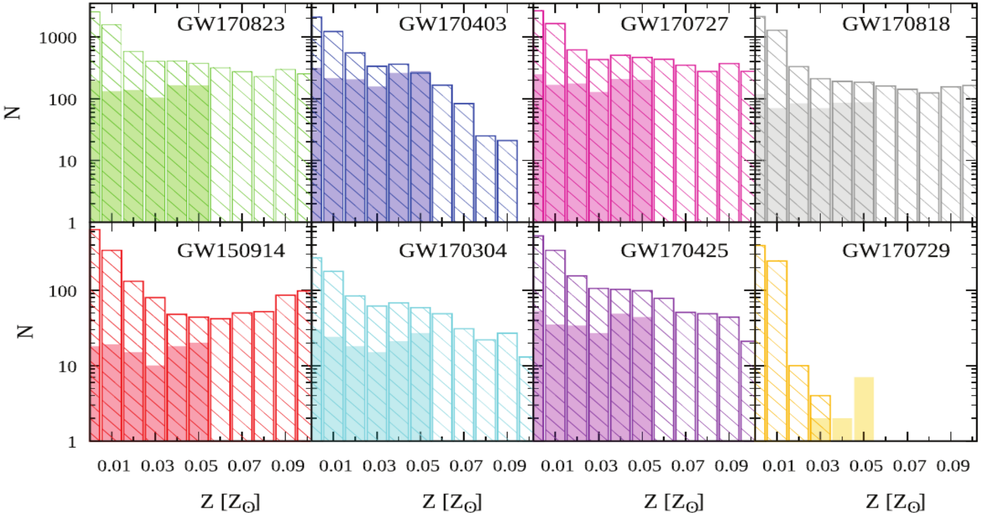
L. Graziani[1,2,3]★ R. Schneider[1,2,4] S. Marassi,[1,2] W. Del Pozzo[5] M. Mapelli[6,7,8] and N. Giacobbo[6,7,8]

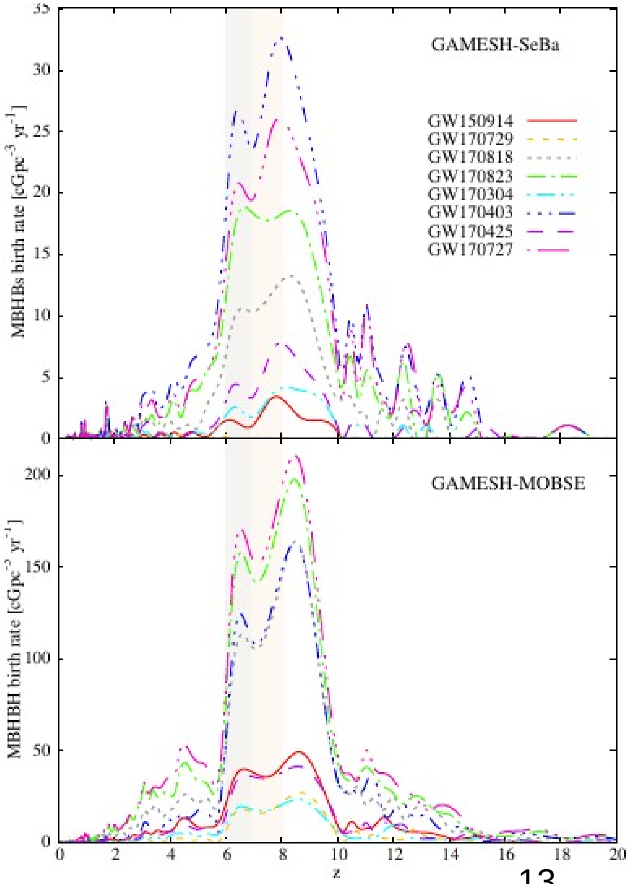
Monthly Notices of the Royal Astronomical Society
MNRAS **495**, L81–L85 (2020)

SeBa
MOBSE
Kroupa
Kroupa 01, MNRAS, 322, 2

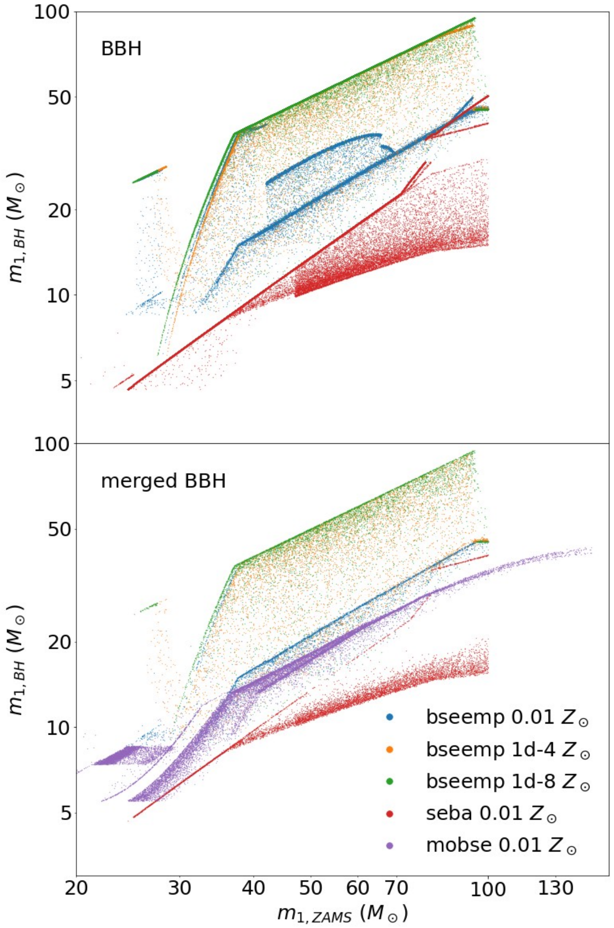
Statistical evidence of a high formation rate during reionization!

Are we probing high-z, low metallicity environments with coalescence of massive stellar binaries?

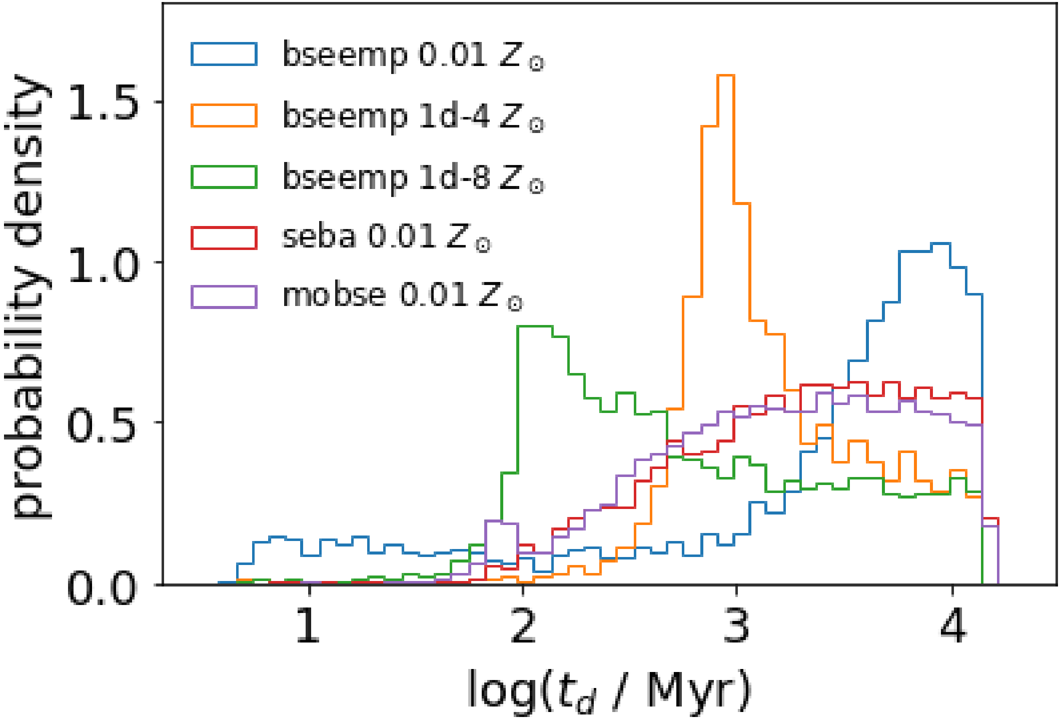




BSEEMP: a new BPS to explore low metallicity binaries



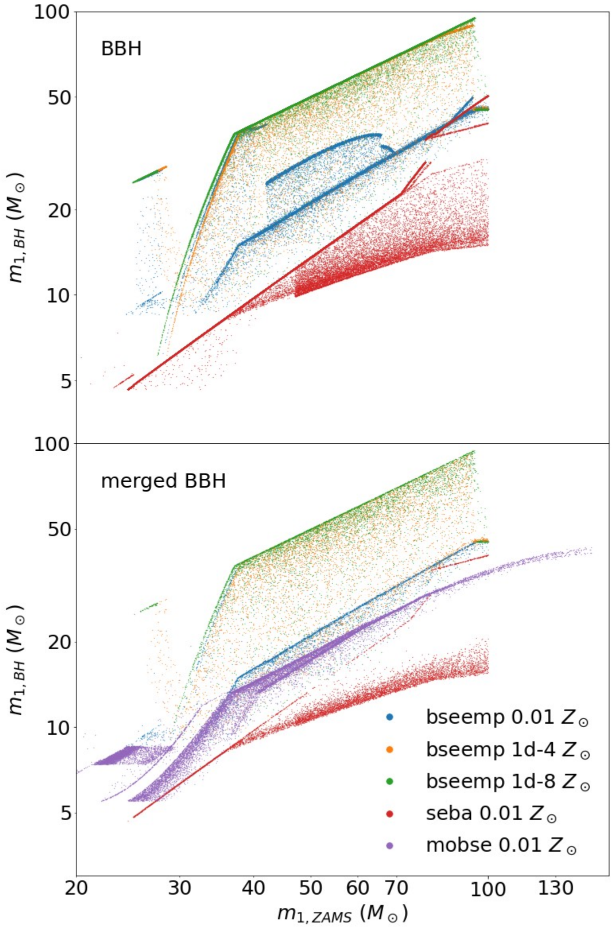
Ruggero Valli, LG, R. Schneider, MsC Sapienza.



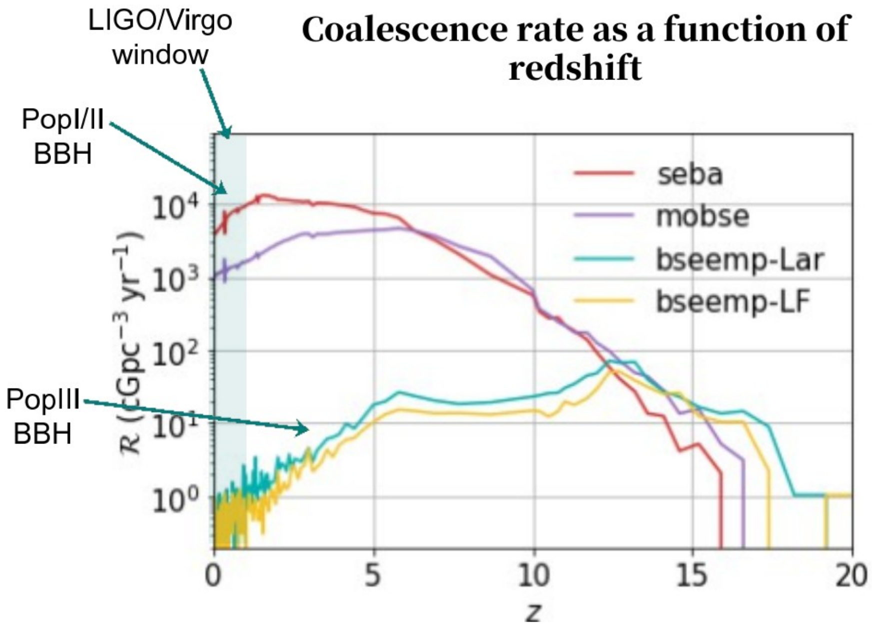
Low-Z binaries during EoR with long delay times would be a natural channel to explain high-mass coalescing binaries already in O3!

BSEEMP: Pop III binaries

Ruggero Valli, LG, R. Schneider, MsC Sapienza.



Coalescence rate as a function of primary BH mass



BSEEMP

PopI/II: Kroupa

PopIII: Larson o logflat

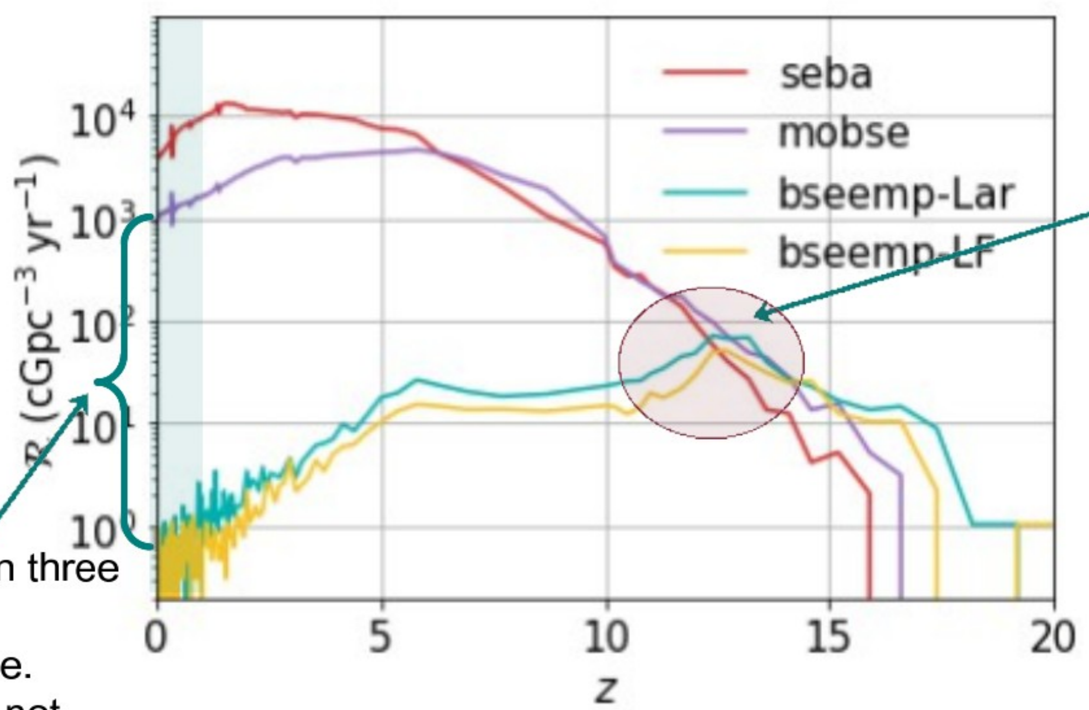
Larson 98, MNRAS, 301, 2

Low-Z binaries during EoR with long delay times would be a natural channel to explain high-mass coalescing binaries already in O3!

BSEEMP: Pop III binaries

Ruggero Valli, LG, R. Schneider, MsC Sapienza.

Coalescence rate as a function of redshift: comparing Pop II and Pop III events

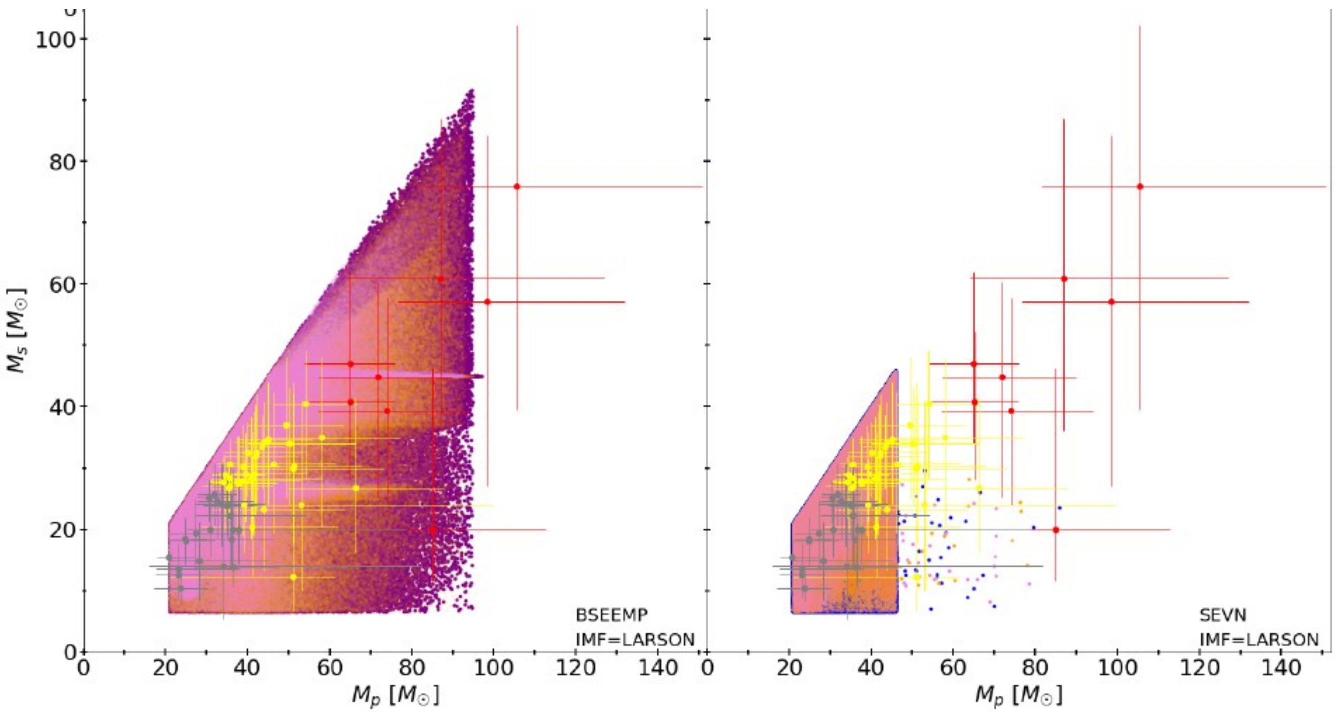


Higher coalescence rate at 10<z<14. Could be measurable with ET.

More than three orders of magnitude. Probably not observable today.

SEVN: another BPS to explore low metallicity binaries

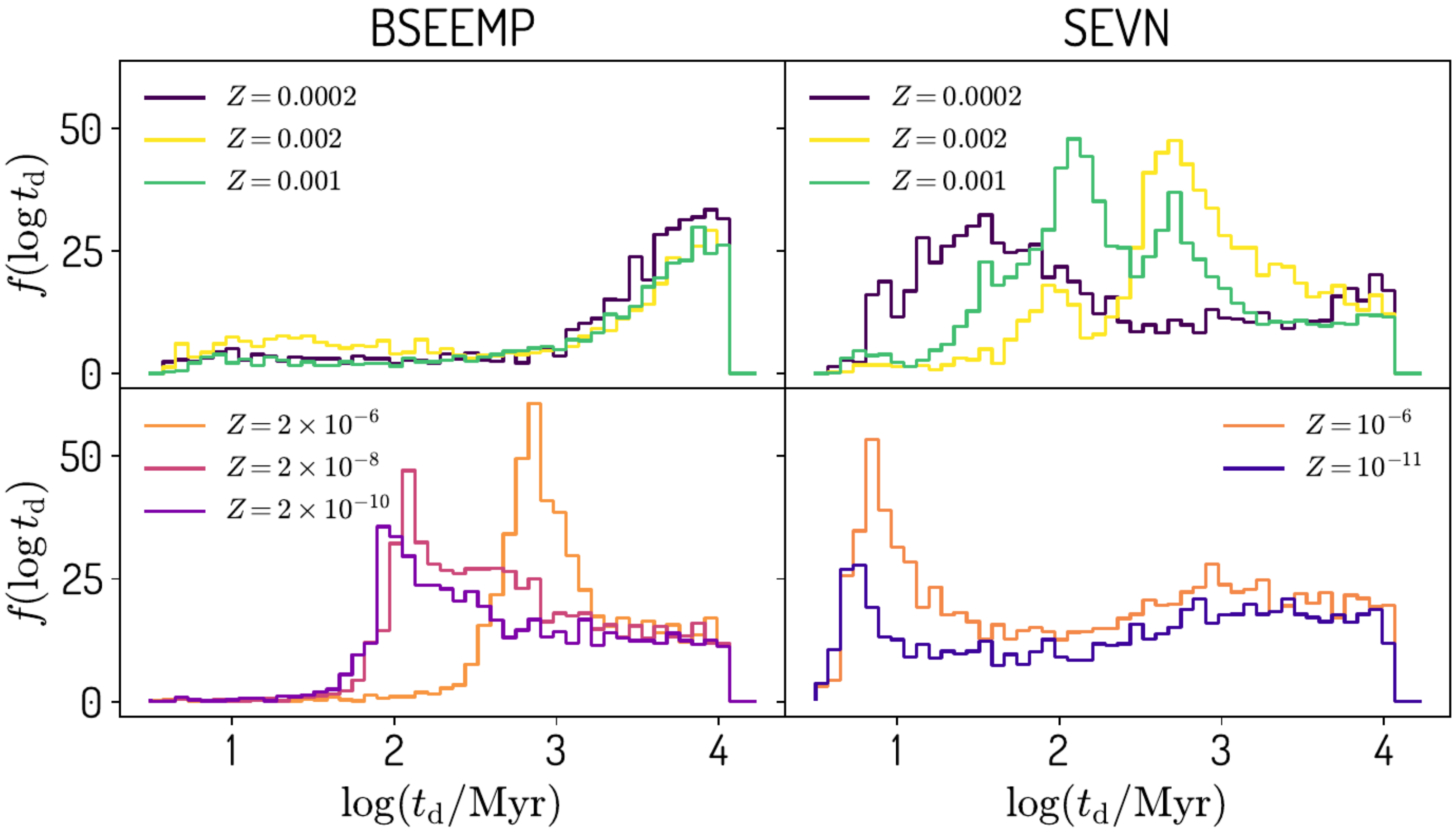
Federico Angeloni, LG, R. Schneider, PhD Sapienza.



Significant differences in mass spectrum

SEVN: another BPS to explore low metallicity binaries

Significant differences in delay times



CONCLUSIONS

- **New signals from the Remote Universe** from both **E.M.** and **G.W.** observations already available and will increase in statistics in the years to come thanks to **new facilities.**

- Discovery of Pop III stars requires **updates in theoretical models of both star formation and galaxy formation**, especially in the low-mass / low-metallicity regimes.

- **Both E.M. detections and sources of G.W. should be interpreted consistently with the assembly history** of our Local Group galaxies →

  BSEEMP/SEVN ready for Pop III binaries while their detectability in GW at z = 0 remains problematic !

- Hydro and RT codes are ready to improve models of IGM reionization but New RT schemes are required to interpret the ISM ionization and spectral signatures of Pop III stars.

- Detailed dusty physics on galactic scales of the ISM → low scale metal enrichment affects Pop III in big galaxies.

- **Not the whole story**: improvements can be made both on Galaxy models and BPS Stellar models to predict new kind of signals as they will be discovered by future facilities.